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A Road Map for Civil Engineers towards Bridge Engineering Through Academic Education and Professional Training

Akbari, R.[1*] and Maalek, S.[2]

[1] Ph.D. in Structural Engineering, Senior Bridge and Structural Engineer, Road Maintenance and Transportation Organization (RMTO), Tehran, Iran.
[2] Lecturer, School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran.

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ABSTRACT: It is common in many countries that engineers having an academic degree in Civil Engineering are appointed responsible for different tasks related to Bridge Engineering. However, there are serious questions about whether formal university courses in civil engineering could cover the needs of a bridge engineer to fulfill his or her job successfully. Regarding the recent significant advances in the theory and practice of bridge engineering, the answer is clearly negative. Indeed, there is a huge gap between the knowledge of a typical graduate -having a Bachelor's degree in civil engineering or a Master's degree in structural engineering- and the knowledge expected to be acquired by an engineer involved in various bridge engineering activities. This paper attempts to bridge this gap by introducing a road map through a proposed program of academic education and professional training. The proposed program has been dealt with in some details in the hope of opening a chapter for further scientific discussions and researches, as well as actual implementation, evaluation and improvement. The suggested programs contain a series of lessons defined within a number of modules. Universities across the world are encouraged to present such courses. Industrialized countries can play a paramount role in this process by presenting Master's courses not only for their Native students, but also for students from developing countries. They can also contribute to training courses to be organized by authorities in developing countries.

Keywords: Bridge Engineering, Civil Engineering, Education and Training, Master's Course.

INTRODUCTION

The importance of bridges as vital elements of transportation lifelines cannot be over emphasized. Bridges and tunnels are the most costly and strategic elements of highways and railways. Any disruption in bridge serviceability may lead to irreversible consequences. Human health is taken for granted for many until it is threatened; likewise, many bridge authorities across the world concern seriously about a bridge health, only when it is somewhat deteriorated through negligence. When preventive measures are not effectively implemented, any minor deficiency may spread so widely

* Corresponding author E-mail: rakbari@ut.ac.ir

that repair measures may become difficult, costly, time consuming and even disruptive. The budget assigned to such repairs in order to rehabilitate such bridges will limit the budget that need to be spent for infrastructure development programs (Maalek, 2005).

The so called Bridge Engineers are considered to be technically responsible for all the engineering works during the life cycle of bridges. However, a question may arise that "*Who is a Bridge Engineer*?" At the first glance, it may seem to be a simple question with obvious answer; since many supposedly believe that an experienced *"Civil Engineer"* can be appointed as a *"Bridge Engineer"* in charge.

No internationally agreed definition is at hand to identify the areas of knowledge and responsibilities of bridge engineering profession. On the other hand, there are still only a few specialized and standardized courses leading to an academic degree in bridge engineering worldwide. Our predecessors who founded "ecole des ponts et chaussee" as a result of the experiences gained during the formation of "Corps of Bridges and Roads", had already recognized the importance of academic training in the development of infrastructure after the grand revolution.

There are some programs aimed at forming bridge engineering. For instance, the International Master in Design and Construction of Bridges (Máster Internacional en Proyectos y Construcción de Puentes) has been offered digitally by Zigurat e-learing (in Spain), catering mostly to the South American market. The goals of this program have been described as follows (Program brochure, 2015):

- Select building materials that are best suited to different types of conventional bridges depending on the geometry and structural aspects involved.
- Understand the criteria for modeling bridges in two and three dimensions (2D and 3D).
- Apply international regulations for the design and construction of bridges.
- Incorporate the different actions of vehicular and pedestrian type contemplated in the design of bridges, as well as the presence of such exceptional actions such as earthquake, wind, water and snow.
- Perform design of superstructure and substructure of different reinforced concrete, prestressed or steel-composite bridges.

Among few specialized courses in Bridge Engineering, one may refer to the Master's courses that have been presented for more than 40 years in the University of Surrey, U.K (see Table 1). The program is approved by the ICE and IStructE as meeting the requirements under UK SPEC for periods of Further Learning leading to Chartered Engineer status (Postgraduate Prospectus, 2005). A newly established Bridge Engineering degree in Master's level has also been implemented in the State University of New York at Buffalo, under support provided by FHWA (see Table 1). The program has been initiated from 2010 and some few specialized courses have been offered. Establishment of this new program can be regarded as an indication of the importance of the subject matter of the present work. However, more investigations are still needed, since a study of the above mentioned Master's programs reveals that they do not sufficiently cover some key areas of learning to meet the needs of bridge engineers.

However, at large, those involved in the design, construction and management of bridges have rarely passed such courses. Depending upon the educational system, the definition of a bridge engineer may differ from country to another. Although one may not find a universally agreed unique definition for the profession of Bridge

Engineering, one of the possible definitions may be given as follows:

"A Bridge Engineer is a Civil Engineer (having a bachelor's or master's degree in Civil or Structural Engineering) who holds a professional license –obtained after passing of some professional training courses and specific duration of on-site training under guidance of a licensed bridge engineer - that allows him/her to undertake responsibilities in some aspects of the bridge analysis, design, construction, serviceability, maintenance, retrofit and demolition".

Such an engineer should attend and meet the requirements of additional professional training programs after gaining experience as a practicing engineer under close supervision of a recognized licensed engineer or engineering firm for a period of 3 to 5 years to qualify for entering into professional examination in this field in order to be allowed to work as a professional licensed engineer. Such a procedure is common in industrialized countries but differs somewhat in developing countries.

Although different aspects of civil engineering educational programs and curriculum have been investigated in the past, to the best knowledge of the authors, no documents on pathology of training subjects related to bridge engineering is available. Jessen (1984) investigated what should be the civil engineer's role in resolving the infrastructure problems. Qingguo and Youcheng (1984) discussed on traditions of bridge construction technique and modern bridge engineers of china. Mickleborough and Loi (1987) presented in detail the design and implementation of a full-time, 15-week bridge engineering course planned and implemented at the University of New South Wales in Australia to upgrade the technical skills of some 60 mid-career bridge design and construction engineers from the Indonesian Public Service. Whiteside (1988) investigated transportation requirements of civil engineers knowledge and demonstrated the education and training programs for senior transportation engineers. Francis (1993) investigated the professional and educational systems in Canada relative to the training of civil engineers at the University of New Brunswick and the evolution of the civil engineering program over a period of 40 years from 1952 to 1992. Riley and Pickering (1995) reviewed the events which have given rise to the need for an undergraduate course module for civil and environmental engineers in 'professional development skills' (PDS). They proposed a framework for PDS which integrates the best of existing programs with new material relevant to the needs of tomorrow's engineers.

Table 1. Specialized courses in Bridge Engineering as being presented in the University of Surrey (UK) and in the State University of New York at Buffalo (USA)

University Name	List of the Specialized Courses
The Univ. of Surrey	● Bridge deck loading and analysis ● Bridge management ● Long span bridges ● Steel and composite bridge design ● Prestressed concrete bridge design ● Durability of bridges and structures ● MSc project on bridge topics
The Univ. of New York at Buffalo (each course has 3 credits)	■ Emerging technologies in bridge engineering ■ Bridge engineering 1 and 2 ■ Advanced concrete materials ■ Bridge/highway infrastructure management and public policy ■ Prestressed concrete design for highway bridges ■ Engineering project

Objective and Significance of the Subject

As mentioned previously, in a relatively few universities around the world, graduate programs have been conducted at the Master's level in Bridge Engineering. The presentation of Bridge Engineering specialty Master's programs is not widespread at Civil Engineering Departments and the above mentioned few programs does not cover every needs concerning the whole-life-cycle analysis, design and maintenance of different types of bridge structures. Hence, the engineers having a Civil Engineering degree involved in bridge design, construction, rehabilitation, maintenance, etc. need to gain practical experience and build up their knowledge in this field outside their academic education. Bridge engineering is indeed a multidisciplinary subject.

In fact, bridges, as masterpieces of civil engineering structures, deserve much more attentions in university programs. Considering the life span of bridges, there is no doubt about the diversity of issues facing bridge officials responsible for bridge design, construction, serviceability, maintenance, retrofit, etc.

Indeed, there is a huge gap between the knowledge of a typical graduate -having a Bachelor's degree in civil engineering or a Master's degree in structural engineering- and the knowledge expected to be acquired by an engineer involved in various bridge engineering activities. This paper attempts to bridge this gap by introducing a road map through a proposed program of academic education and professional training. The paper is written with an "analytical-descriptive" approach and addresses the training needs for a bridge engineer and explains the extent of related subjects to authorities and engineers. The proposed program has been dealt with in some details in the hope of opening a chapter for further scientific discussions and researches, as well as actual implementation, evaluation and improvement. The suggested programs contain a series of lessons defined within a number of modules.

In fact, it has been attempted here to point out some of these subjects, considering the needs and shortages of training, for experts involved in bridge engineering profession as well as those responsible for teaching of bridge engineering at universities and professional training programs and of course the officials dealing with the construction and maintenance of bridges. Industrialized countries can play a paramount role in this process by presenting Master's courses not only for their Native students, but also for students from developing countries. They can also contribute to training courses to be organized by authorities in developing countries.

A Review of the Current Condition in Iran

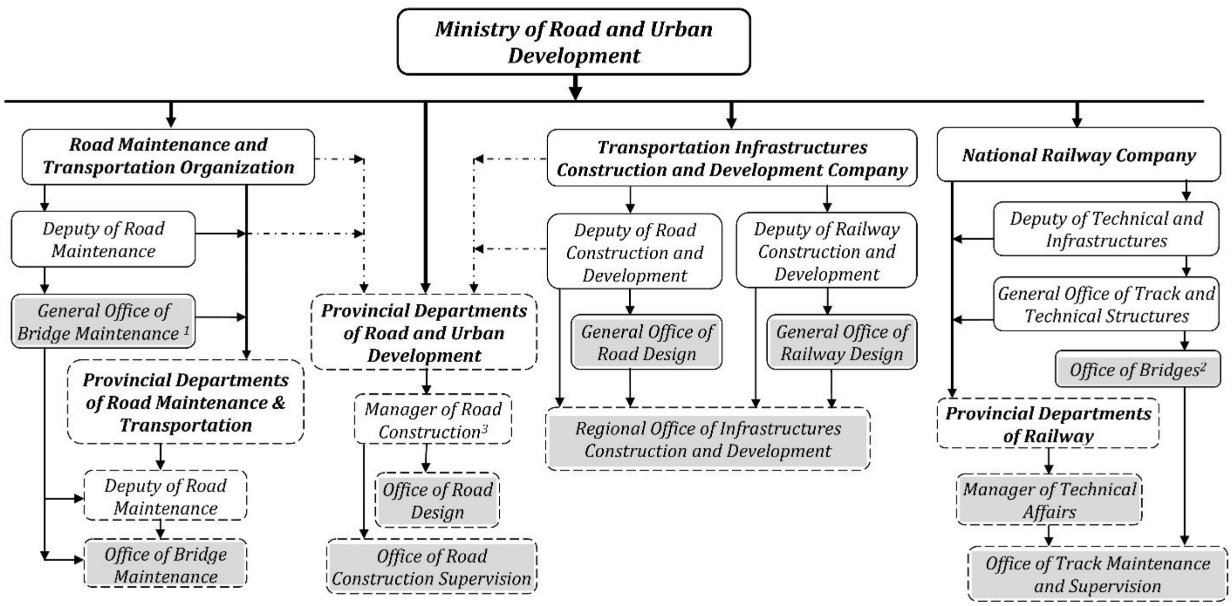
This section is written as an attempt to identify deficiencies in the training system of bridge engineers in Iran that could be equally extended in many parts of the world.

Organizational Issues

In Iran, for more than half a century, highway and railway bridges are considered to be parts of infrastructural development projects planned and budgeted within the framework of national development programs supervised by transportation officials. These projects are usually defined and assigned to firms recognized by the "Plan and Budget Organization" of this country. In many cases, the technical bureau of authorities chooses a consulting engineering firm to carry out the feasibility and design phase studies. The construction phase will be put on tender and the construction works are carried out under the supervision of the consulting engineers. Moreover, a lesser number of bridge projects have been constructed through the EPC contacting system.

The technical bureaus of the local authorities are responsible for operation and maintenance of bridges. It has been realized (Maalek, 2005) that in the design phase, attention is mostly focused on the initial expenditure rather than the life cycle cost. Since the design and construction teams are not held responsible for durability and maintainability of the bridge, and since there is no comprehensive Bridge Management System (BMS) defined and implemented, maintenance of bridges are usually costly.

The organizational structure of the Iranian Ministry of Road and Urban Development, as the owner and the main authority responsible for all the bridges in the roadway and railway networks of the country, is shown in Figure 1. Here, only the divisions and subdivisions related to the design and maintenance of highway or railway structures (e.g. bridges) are shown (see: Sahrapeyma and Hosseini, 2013).



Notes:

1-Management and maintenance center for all the bridges on the roads network of the country and the BMS room. Budgeting for road and bridge maintenance for provincial departments is carried out here. A complementary supervision on bridge maintenance activities in provincial departments is also implemented.

2-Management and maintenance center for all the bridges on the railway network of the country. No management or maintenance activities on railway bridges are allowed to be carried out by the provincial departments.

3-In provincial departments of road and transportation, only roads and bridges in the regional roads network are included.

-Dashed boxes represent provincial divisions and solid boxes indicate national divisions in road/railway construction or maintenance activities.

-Dashed arrows represent indirect organizational subdivisions and solid arrows represent direct subdivisions.

-Highlighted boxes represent the specific national or provincial offices responsible for design, construction or maintenance of bridges.

Fig. 1. Organizational structure of the Iranian Ministry of Road and Urban Development (only the divisions related to the design, construction and maintenance of highway and railway bridges are shown)

Although there are bridge maintenance organizations responsible for roadway, railway and municipal bridges in Iran, there are several weak points at different levels of their organizational structure that directly affect the condition of bridges. Lack of managers' specialized knowledge, lack of sufficient number of experts in bridge authorities and lack of a general training program for mid-career bridge engineers have resulted in a situation that newly employed and inexperienced civil engineers are usually appointed in bridge repair and maintenance divisions of transportation departments. Unfortunately, there is no clear legal and juridical system that properly defines the responsibilities and evaluates the performance of engineers in different levels of responsibilities. On the other hand, several mistakes can usually be found in both the conceptual and detailed design, retrofitting measures and the maintenance and repair strategies adopted. This issue, although is out of the scope of this paper, is an important problem which has direct relation to the training structure of the university educational programs and mid-career continuous trainings.

Training System

Figure 2 shows a list of some of the topics taught in undergraduate Civil Engineering programs. Apparently, this list only includes topics, related to our discussion. In Iran, all that a student may take in his/her Bachelor's degree in Civil Engineering or Master's degree in Structural Engineering is a single optional course entitled "*Bridge Design*" or "*Fundamentals of bridge Engineering*". For those who have not carried out their thesis research on a subject related to an aspect of bridge engineering, this is by no means sufficient.

Hence, many graduates with a very primitive knowledge of bridge engineering enter the industry, consulting engineering firms, contractor companies and executive sectors of this country. This is in contrast to the fact that the subjects related to bridges are so extensive that by no means all, or even parts of the required information could be taught during a single university Master's program.

Management Issues

The existence of a rather large number of bridges in the transportation networks of Iran is mainly due to the existence of mountainous areas. At the same time, due to the concentration of population in large cities, resulting in quite heavy traffic, the town halls have constructed a rather large number of flyovers within populated cities.

Depending on topographical/geographical situations, similar conditions exist in other countries with smaller or larger number of bridges. In some regions, a special type of bridge may be dominant to match the suitable span lengths (e.g., longer span bridges in waterways or shorter span bridges in deserts). A good statistics about the number of bridges in fifteen countries, in which a bridge management system operates, can be found in the report by Adey et al. (2010).

Every year millions of USDs are spent on the construction of new bridges and repair and maintenance of existing bridges in the world. Nevertheless, bridge damage and deterioration is growing in an alarming rate. Bridges as important assets of every country deserves to be designed, built and maintained by engineers and contractors with greatest expertise. However, in practice, conditions are not so ideal in some countries. Sometimes from the beginning of the design process and later in the construction and maintenance phase engineers without the required expertise are appointed for the job. This directly affects the performance and service life of these assets. Although the number of bridges that have collapsed is rather small compared with the number of existing bridges, it must be noted that these structures are usually designed for a typical life span between 100 to 120 years. However, the actual average age of engineered bridges constructed in this country in the second half of the 20th century is noticeably less than that. Hence, in the next few decades the real performance of those bridges will be realized more clearly. Also, the performance of the designers, builders and the authorities responsible for their construction and maintenance will be better known. However, considering the measures taken to maintain and repair the bridges in order to extend their life span, the speed at which the bridges are deteriorating has slowed down to some extent.

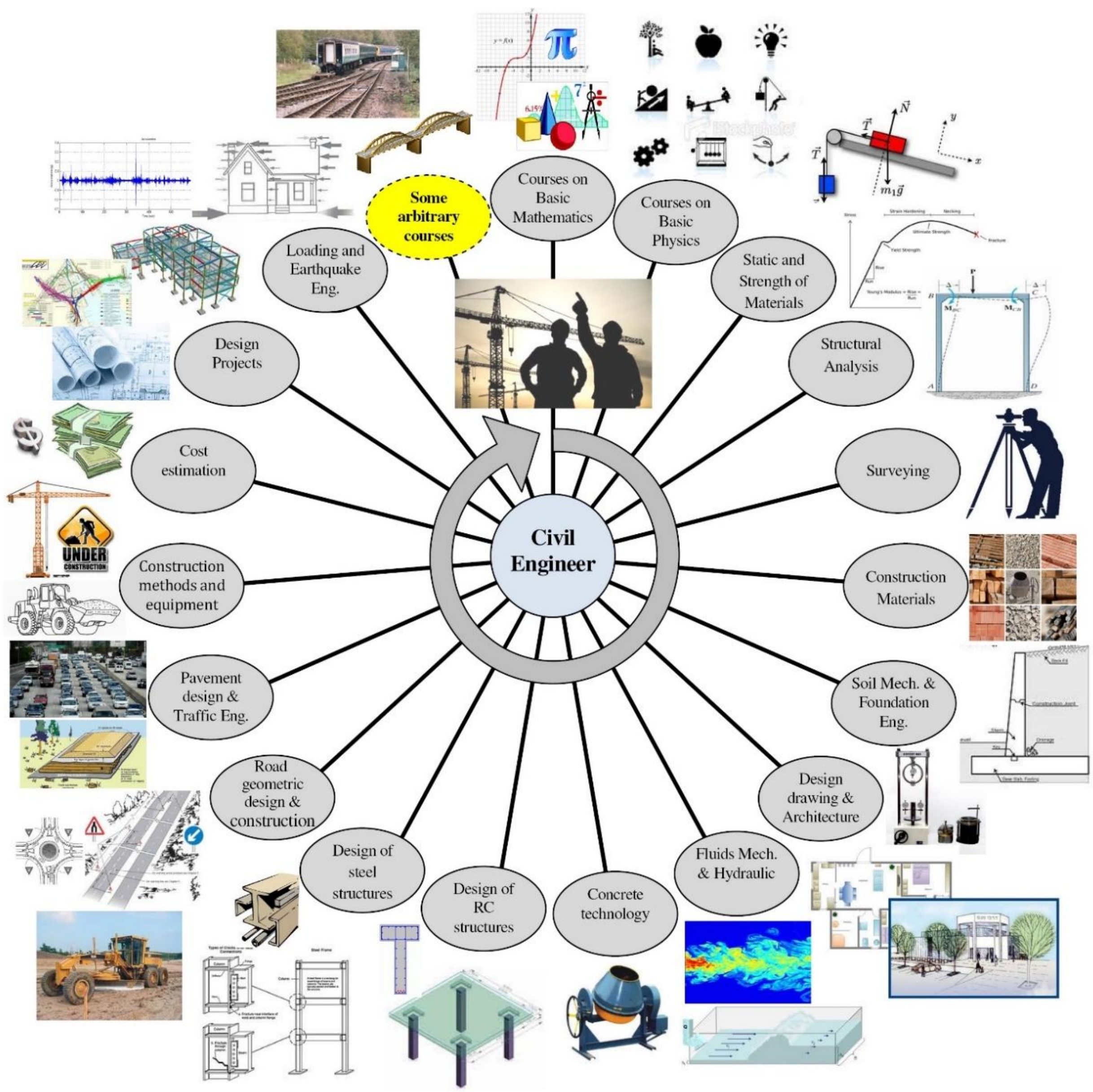


Fig. 2. List of topics usually taught to Civil Engineers at undergraduate level

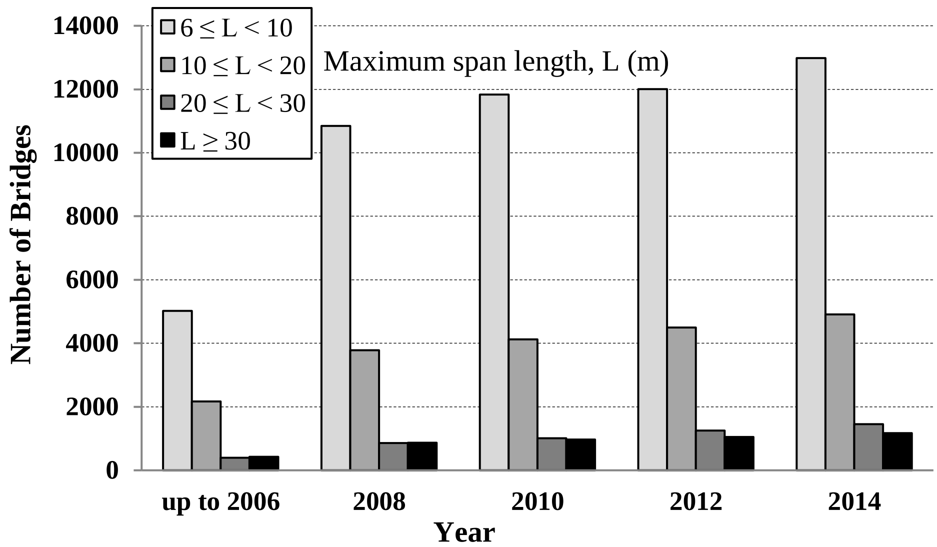


Fig. 3. Statistical population of road bridges in Iran road network (RMTO annual report, 2015)

The statistical population of road bridges in Iran road network has been shown in Figure 3 (RMTO Annual Report, 2015).

Owing to their professional and research involvements (e.g. Maalek, 2005; Akbari 2013 and 2015; Maalek, 2010), the authors are reasonably aware of the current condition of bridge management in Iran. Furthermore, on the basis of their participation and contribution to a number of international programs and membership in international bodies dealing with road transportation and bridge engineering (e.g. PIARC working group on road bridges, International training programs for developing countries, International bridge associations and societies, etc.), it can be concluded that the general condition of bridges and bridge management in other developing countries is not better than this country. For instance, present condition of highway bridges in Vietnam has been reported by Hai et al. (2007). Their investigations showed an overall picture of existing bridges in poor physical condition, thus providing poor service to users. It is the first impact of poor training system for bridge engineers and lack of a comprehensive bridge maintenance system. Specific problems and proposed maintenance strategies have been suggested by Hai et al. (2011) for reinforced concrete bridges in Vietnam. Apparently, no one can implement such strategies except trained and experienced bridge engineers. Similar situations exist in the neighboring countries of Vietnam and many countries in the North Africa and the Middle East.

Knowledge and Training Needs For Bridge Engineers

The First Lesson: "Fundamentals of Bridge Engineering"

As mentioned above, scientific fields related to bridges are so vast that this discipline deserves a separate curriculum leading to a Master's degree in bridge engineering. Of course, the diversity of scientific subjects related to these structures has grown to such an extent in the last 50 years that between 10 to 20 specialized university courses can be devoted to training bridge engineers exclusively. This of course must be planned by educational authorities in the industry as well as in higher educational institutions.

At the first glance, Structural Engineering may be considered by many as the specialty closest to Bridge Engineering, but there are considerable differences between what a graduate of Structural Engineering learn in the university and what a bridge engineer encounters in practice. Bridges are considered to be one type of special structures and hence have special design codes. Also, an optional course in bridge design and practice usually included in the Master of Structural Engineering degree, explains only some of the general, but preliminary, concepts of the behavior, design and construction of bridges. It can confidently be emphasized that structural engineers having passed an introductory course on bridge engineering as one of several courses of their studies, will not be fit to act as a successful bridge engineer due to their lack of knowledge concerning the most fundamental technical subject matters that they shall inevitably encounter in practice.

Similar to other type of structures, after making initial strategic decisions to construct a bridge, the first stage in the formation of a bridge is its conceptual design and the selection of its structural materials and system. Also, the geometrical concepts, span lengths, choice of the type of foundations and the design of main load carrying elements of bridge including its deck, bearings, columns, retaining walls, etc. is dealt with comparatively in the design of bridge alternatives to enable the selection of the most appropriate solution to the problem before proceeding with the detailed design. In Civil Engineering Departments, during a course entitled “Bridge Engineering” or “Bridge Design”, some of these topics are dealt with from a general perspective. The syllabus could include (Maalek, 1991) a brief review of the history of bridge engineering, followed by an introduction to different bridge systems, bridge forms, materials of construction and the load paths under different actions. Steel and concrete bridges with different structural and deck systems are to be introduced in more details. Common types of bridge piers and abutments are also covered briefly. Introductory information on bridge bearings and expansion joints, bridge foundation design and construction need be provided. Also, the importance of the establishment of a suitable Bridge Management System need be emphasized in this elementary course. The course is to be accompanied by a project work with a variety of choices. A very common practice is the design of a simple bridge as the project work (usually voided slab, slab-on-beam or composite deck bridges supported by column and cap-beam bents with open or closed abutments). Looking at the case optimistically, it can be expected that civil or structural engineers who have passed such an optional course, should have a basic understanding of the fundamentals of bridge engineering. This is the turning point of the pathology in the academic knowledge of civil engineers who may work as bridge engineers.

In the followings, we assume that a civil or a structural engineer has passed “*The first lesson*” as discussed above, which focuses on the fundamental concepts of bridge engineering. However, the above basic knowledge is by no means sufficient for such an engineer to fulfill his/her job successfully and satisfactorily in this field.

The Second Lesson: “Bridge Superstructure”

The structural elements of a simple bridge can be categorized in three main groups: i) the deck, ii) the piers and abutments and iii) the foundation. The decking methods of bridges are also very diverse in terms of the material, shape, structural system and construction method. Since they may exhibit complex behavior, a thorough understanding of the behavior of different types of bridge decks will substantially help bridge engineers in their design, construction and maintenance works. The simplest small span bridge decks exhibit a behavior that can be approximated by the theory of orthotropic plates. Therefore, in specialized books on bridge design, the theories of plate bending are briefly reviewed. The knowledge of a structural engineer who has not passed the first lesson, but has attended an optional course named "the theory of plates and shells" does not suffice to correlate the plate analogy to bridge deck analysis. Therefore, it is essential to train bridge engineers in the loading, behavior, modeling, analysis and design of various types of bridge decks as a separate course or special subject that particularly includes reinforced concrete as well as orthotropic steel decking. Also, the yield line theory applicable to slab bridges and arching action for beam and slab bridges need be dealt with. Moreover, a variety of superstructures for small to medium span bridges needs to be treated in some details. One of the most important points to be emphasized here is the design for maintainability and durability as well as the fatigue design and detailing of (particularly steel) superstructures.

The Third Lesson: "Bridge Substructure"

Bridge substructure is another principal part of a bridge consisting of piers and abutments employed to transfer vertical as well as lateral loads to the bridge foundation. They are also extremely influential in the bridge response to actions such as seismic excitation, wind loads, thermal effects, water pressure, etc. Closed abutments in variety of types and forms also perform as the retaining structures for the bridge approach embankments. Amongst various types of piers, single piers or multi-column bents in single or framed types supported on spread or piled foundations are widely used. Substructures certainly perform important role on the safety and the functionality of bridges. Significant damages have been reported as a result of the past earthquakes due to inadequate detailing in the elements and/or connections of substructures. Insufficient support length over abutments or middle-piers, inadequate confinement in RC columns, inadequate ductility and insufficient strength (particularly in shear) are only a few common problems that have been observed in many older bridges in Iran (Maalek, 1998; Maalek, 2010) and have been the main causes of many bridge failures during the past earthquakes across the world. At the first stages of bridge design, i.e. the conceptual design phase, relevant alternative types of the substructure should be considered by the bridge designer. Hence, a bridge designer should be well familiar with various types of abutments and piers to be able to choose the most suitable types for a particular problem amongst several possible alternatives. Great care should be exercised in the teaching of conceptual design principles as well as detailed design. Hence, it is essential to include a course specifically covering substructure types, behavior, analysis, design, construction, maintenance and retrofit.

The Fourth Lesson: "Bridge Bearings and Expansion Joints"

Expansion joints, also known as movement joints, have a key role in bridge performance and behavior. They are also important from the point of view of roadway and railway users.

It is a fact that expansion joints are usually among the most vulnerable parts of bridges. Their service life is usually much lower than the bridge expected service life. This involves significant maintenance and repair costs during the service life of a bridge. The Technical Studies Department of French Highways estimated the maintenance costs for expansion joints in between 7-8 percent of the global maintenance costs of bridges

(Lima and Brito, 2009). Of course, this value is already varying in different countries, even to a peak of 25%. Therefore, the current trend for most transportation agencies is to minimize the number of bridge deck joints as appropriate in both new designs and existing bridge retrofit. However, a vast majority of existing bridges have joints, and most deck joints are problematic; a situation that will continue to exist for many years. Poor detailing and implementation, poor maintenance and lack of proper drainage systems are the main causes for these problems. As a result of a comprehensive field study on about 300 bridges in Iran, Maalek (1998) reported that about 60% of the expansion joints were not properly functional. In the case of a number of long multi-span bridges, noticeable damages had been observed in bridge super structures, bearings and substructures due to thermal effects. Poor drainage had resulted in the deterioration of several bent caps and piers situated under the joints.

Bridge bearings are structural elements located between the superstructure and the substructure to perform three primary functions: i) to transmit superstructure loads to the substructure, ii) to permit longitudinal movement of the superstructure-relative to the substructure- due to thermal expansion and contraction (expansion bearings only) and iii) to allow rotation of the superstructure due to dead and live loads at support positions. Different types of bridge bearings are used on the basis of the type of bridge superstructure support condition. Bearings are hence designed either to prevent relative translational movements (fixed bearings) or to allow such movements (expansion bearings). Among many types of bridge bearings, one may refer to elastomeric bearings, roller bearings, sliding bearings, hinge bearings, rocker bearings, pot bearings, etc. Elastomeric bearings themselves are fabricated in a variety of types and forms to fulfill different tasks. Important quantities such as shear modulus and damping properties should be carefully estimated (Akbari and Maalek, 2009). Proper modeling of bridge bearings is fundamental to achieving any reliable bridge analysis results (Maalek, 2008). Bridge bearings play a paramount role in the bridge response to an intensive earthquake. Superstructure unseating has been a major mode of bridge collapse during the past earthquakes. Proper design and detailing of bridge bearings can perform a vital task of saving the superstructure unseating (Akbari and Maalek, 2016; Aria and Akbari, 2013).

The lesson shall focus on introducing different types of bearings and expansion joints and their properties, behavior, modeling, analysis, design, fabrication, installation, maintenance and operational performance. Moreover, some of the preventive measures for increasing their service life need to be discussed.

The Fifth Lesson: "Railway Bridges"

For all bridges and more specifically railway bridges, another important issue which researchers have attended to is the vehicle-bridge or train-railway-bridge interaction. In this research area, basically the vehicle-deck or train-railway-deck interactions and their dynamic effects are studied and some fundamental concepts are discussed. Depending upon the materials of construction of the superstructure and decking and whether rail track ballast is used or the rails attached directly to the superstructure, knowledge of this interaction helps significantly in modeling and analysis of bridges. The discussion should extend to developing propulsion or suspension systems of trains and other vehicles, understanding how the smoothness or bumpiness of the pavement on the deck affects the response of the bridge, studying the amount of impact caused by vehicles on the bridge deck and in a nutshell, getting acquainted with the philosophies behind some related concepts of design codes in connection with the design of the deck and its elements, investigating the above problems in the case of curved railway bridges, and so on. As a result, civil engineers are not well acquainted with these problems. For bridge engineers involved in similar projects, e.g. railway bridge design and maintenance, a good understanding of bridge-vehicle interaction is essential.

The Sixth Lesson: "Bridge Dynamics"

Bridge vibration depends upon some characteristic parameters of the bridge structures, foundation, soil-structure system as well as the nature and quantity of applied loads and actions and environmental effects. Vibration of bridges under the influence of live loads and their dynamic effects are of concern to bridge designers and the authorities responsible for bridge operation and serviceability; particularly in the case of long span bridges. Bridge codes give simple hints on the limitation of the live load displacements. However, the frequency of vibration of the deck is also of importance in connection with the limits of vibration that can be felt by human and can cause human concern. These vibrations may be unpleasant and even dangerous. In addition to the effects of the passing traffic, on and in the vicinity of a bridge, other ambient forces such as wind or actions caused by natural disasters (e.g. earthquakes and hurricanes) result in the dynamic response of a bridge. Not only a bridge engineer should be familiar with probable dynamic actions and their interaction with the bridge, they need to be acquainted with the dynamic behavior, analysis and design of bridges. The history of bridge engineering has recorded bridge failures caused by wind (e.g. the Tay bridge disaster partly due to the lack of consideration of wind loads on the body of trains and the Tacoma Narrow bridge collapse due to vortex shedding). Several bridge collapses and substantial damages caused by earthquakes have been reported in the seismic prone parts of the world. The study of the dynamic behavior of bridges is a prerequisite for the design of bridges to exhibit a satisfactory dynamic response under the application of such actions. Also the performance of bridges in the long run has become the subject of active researches in recent decades in the framework of performance based design. Although many concepts of structural dynamics are applicable to bridges, there are quite a number of dynamic problems that are usually more important in bridges than in building structures and hence, are not considered in sufficient depth in courses on structural dynamics. Among these, one may name the effects of dynamic vehicle-deck interaction, uplift wind forces, vortex shedding, multiple support seismic excitation, the effects of the vertical component of ground motion, and many design criteria particularly suited to bridges that are not relevant to building structures. Also problems such as the particular forms of different bridge structures, whether straight, skewed, curved or arched, the effects of geometric irregularities (Maalek et al., 2009; Akbari and Maalek, 2010), soil-abutment interaction, effects of elastomeric bearings can be included. On this basis, it is necessary for bridge engineers to get familiar with the dynamic behavior, analysis and design of bridges through a specialty course on "Bridge Dynamics".

The Seventh Lesson: "Bridge Hydraulics"

In the design of bridges passing over waterways, the selection of bridge location, span lengths, type of piers and foundations and the free height for the underpass is to be made with due consideration of hydrologic data, hydraulic analysis results, geotechnical conditions and the underpass traffic and discharge. For economic and technical reasons, it is usually not feasible to construct a bridge with a free span length greater than the total width of the river or the stream that may occur during a flood. Middle piers are usually used as appropriate. Where the situation allows, approach embankments may be continued to some extent. Such bridge substructures are exposed to permanent or seasonal water pressure from river or flood flow. In the design of bridges crossing a waterway, several additional studies and pre-design controls are required in comparison with other bridges. The layout, shape and inclination of bridge piers should be chosen with great care. Bridge scour has been and continues to be a big problem facing bridge engineers. It is of vital importance to find a realistic estimation of the scour depth to enable an appropriate choice of the type of the pier foundation and its top level and depth. Estimation of long term demand of water flow discharge and overpressures on the substructure elements of the bridge should be taken into account. This proposed lesson is considered to introduce to students and engineers such matters as the fundamental concepts of bridge hydraulics, hydraulic modeling, analysis and design, engineering hydrology, hydrologic data collection and site investigation, bridge scour analysis and design, investigation of the dominant regime of river bed and surrounding areas, the geometric design of elements having contact with water, investigation of deep water currents in bridges built in seas or over rivers, geotechnical considerations in seas, etc.

The Eighth Lesson: "Geotechnics and Foundation Engineering for Bridge Engineers"

The conceptual as well as detailed design and construction of bridges are highly influenced by the properties of the substrate soils, the geotechnical aspects of the construction site and the choice of relevant type of foundation and their method of construction. Civil engineering courses in soil mechanics and foundation engineering mainly focuses on subjects suitable for building structures. Bridge authorities face several problems that are not covered in such courses in general civil engineering programs. Problems arising in sites with difficult soils and liquefiable ground or bridges over waterways need specialized attention. Also, different foundations for open and closed abutments and the deep foundations typically used as bridge foundations should be dealt with in a separate course to familiarize students and civil engineers with various aspects of the analysis, design and construction of bridge foundations. Usually, the reports of field studies and laboratory tests are prepared by the consulting engineers responsible for geotechnical studies -usually by a firm different from the firm responsible for the bridge design- without any expert advice concerning the suitable type of foundation and foundation layout. These reports are very typical, no matter whether carried out for a building or for a bridge! Moreover, the design of bridge foundations is carried out based on reports of the site investigations and laboratory tests of the site soil by civil or structural engineers who lack the basic knowledge of geotechnical engineering. The design and construction of different shallow and deep foundations in different types of soil deserves to be taught to bridge engineers exclusively. The course should include the manner in which site soil investigations need be carried out. Also geotechnical and hydraulic considerations in the design of bridge foundations are to be of central attention. The syllabus is supposed to cover phenomena such as liquefaction, lateral spreading and subsidence as well. Neglecting hydraulic and geotechnical issues have resulted in several cases of bridge failure due to floods or earthquakes.

The Ninth Lesson: "The Seismic Behavior, Analysis, Design and Retrofit of Bridges"

In seismically active countries, including Iran, the philosophies behind the seismic design practice for structures and, of course, bridges are of vital importance. The insight of the bridge engineer into the seismic behavior and design of bridges is directly reflected in actual bridge engineering practice. As a consequence of destructive earthquakes happened in the US and Japan between 1985 and 2000, design codes focused on performance weaknesses and the real needs and shortcomings of design requirements. Billions of dollars were spent on researches on these issues resulting in the fact that the lessons learned from these earthquakes transformed the philosophies behind the seismic design of bridges. Displacement, performance and damage based design methods were developed together with new approaches to the problem leading to some fundamental changes. Previous codes were hence, revised and rewritten. Particular attention has to be paid to the seismic design philosophies and practice in the framework of the specialty training or Master courses.

The Tenth Lesson: "Bridge Management"

With the growing demand for construction of roads and railways and consequently, the increase of the number of bridges in developing countries, it has become a necessity to increase the lifespan and durability of bridges through proper management. Those engineers involved in the design, construction and maintenance of bridges need to be familiar with the concepts of the so called "Bridge Management System (BMS)". Bridges are to be considered as sustainable structures and the design and construction of bridges must accord with the concepts of sustainable development. Therefore, it is essential to include the teaching of the concepts related to the design and construction of durable structures to bridge engineers. Also, in order to increase the life span of bridges with a minimum effort and cost, the maintainability of bridges should be considered as a major factor in the design stage. Bridge maintenance is an important element of any BMS. It is generally necessary to record all events in the service life of these structures and to organize the technical and health information of bridges into a suitable data base. Indeed, bridge management is a system under which a bridge is monitored and appropriate measures are taken timely throughout its life cycle. This matter was given attention in developed countries years ago and today they are used as a maintenance management system for structures (Miyamoto and Motoshita, 2015; Adey et al., 2010). Concepts of the BMS should be at the top of the agenda both in specialty training courses or graduate programs. Hence, the syllabus should include training in inspection, evaluation, field tests, completion of bridge inventories, the processing and interpretation of inspection and inventory records, health monitoring and other related activities (Maalek, 2005 and 2007). An inspector should have a deep understanding of the behavior of these structures in different environments and under different loading conditions.

The Eleventh Lesson: "Bridge Maintenance and Repair"

A special training program is needed for bridge engineers to get acquainted with the methods and techniques of bridge maintenance and repair. This may include reinforced concrete, steel, and masonry and wood bridges. Common causes of deterioration and the resulting consequences should be discussed in some details. In the case of reinforced concrete bridges, particular attention should be focused on such phenomena as carbonation, chloride attacks, alkali-silica reaction, et cetera. In addition, special problems typical to pre-stressed bridges should be taken into consideration. The inspection, tracing and repair of fatigue damaged areas need special training that should contain an introduction to fatigue behavior of steel and reinforced concrete bridges (see: Akbari, 2013; Akbari and Rafiei, 2014). Environmental effects on the fatigue behavior should also be discussed and the techniques for fatigue monitoring and repair measures must be introduced. Moreover, in the maintenance and repair, emphasis should be placed on the durability of bridges which is currently an important industry in the world. It is hence appropriate to train bridge engineers the use of various devices and techniques available in the industry for the repair of bridges.

The Twelfth Lesson: "Bridge Rehabilitation and Retrofit"

At the same time, there are many bridges in different countries including Iran built in the twentieth century that do not satisfy current design regulations incorporated in recent design codes and guide manuals, both seismic (Maalek, 2008) and non-seismic. It is necessary that their loading capacity be estimated, their vulnerability be assessed and their weaknesses be identified. After a realistic estimation of the remaining life of the bridge, a rather large number of such bridges should be repaired, retrofitted or strengthened. This requires a good familiarity with the basic concepts of the seismic and non-seismic strengthening, rehabilitation and retrofit of bridges which have fundamental differences with other types of structures, e.g. buildings, and must be taught in a separate course as a specialty subject. Getting familiar with building materials with new technologies in the rehabilitation and strengthening process of bridges (e.g. different composites, alloys, nano-based and smart materials, different seismic or non-seismic protective and control devices such as dampers, vibration isolators, etc.) is also in this category. This consists of a great amount of educational materials to be presented in this lesson. This course should also include inspection of bridges with the aim of teaching students how to prepare, execute and analyze inspection results. At present, the absence of subjects on bridge rehabilitation and retrofit from university courses in civil engineering is largely felt. Considering the financial consequences of any decisions made in this regard, it is a necessity for bridge engineers, experts and authorities responsible for bridges to be familiar with the know-how of this subject deeply.

The Thirteenth Lesson: "Advanced Bridge Design"

Basically, classical subjects of the university courses in the design of steel and concrete bridges deal with simple bridge superstructure and substructure systems. However, in many cases for medium to rather long span bridges, truss bridges, arched bridges or pre-stressed concrete bridges are well known as potential alternatives, considering technical and financial aspects. A bridge designer must be thoroughly familiar with various methods of construction of such bridges; since the decision on the construction method has to be taken in the design stage. Therefore, the design and construction of truss, arched (both deck-type and tied) or pre-stressed bridges is also another important topic that bridge engineers should learn in some details. It should be noted that pre-stressed concrete is usually discussed in an optional subject in Master's courses on structural engineering. Advanced topics in the design of bridge substructures and foundations are to be given with a design project work. Here, an introduction to the design and construction of cable stayed and suspension bridges are considered to be presented as well.

The Fourteenth Lesson: "Long Span Bridges"

Mainly based upon the geometric considerations of the roadways and railways and topographic conditions, the construction of bridges with long spans may be inevitable. Different types of cable stayed or suspension bridges are the most famous ones in this category. Considering financial aspects and the time and efforts necessary for the construction of such bridges, these bridges usually are of strategic importance and are planned to have a typical service life of approximately 200 years. These bridges are associated with their own special problems and there are special considerations to be taken in their conceptual design that should incorporate a preplanned construction approach as well as an appropriate choice of monitoring and maintenance strategy. Among special issues that should be considered in the design stage for such long span bridges are the dynamic and seismic behavior and design, aerodynamic considerations, design to withstand wind including wind tunnel tests, and in particular, their construction methods. There are so many materials to be mentioned about these issues that deserve a separate university or training course. Thus, a lesson on the design and construction methods for long-span bridges can also be incorporated in such a comprehensive educational program.

The Fifteenth Lesson: "Pedestrian-or Foot-Bridges"

In recent years, because of the expansion of the country's road network and increasing number of pedestrian-vehicle accidents in streets of populous cities, in order to make it safe for pedestrians to cross city streets and highways, many pedestrian bridges have been built. Recently, particular attention has been devoted to the aesthetic aspects of pedestrian bridges. New concepts of bridge design have been introduced through the construction of modern pedestrian bridges that may be applied in a larger scale to highway and railway bridges. In developing countries, aesthetically pleasant and easy assemble pedestrian bridges that can be mass produced through modular design and prefabrication may be beneficial for quick and economical solution to the ever-increasing demand for the construction of pedestrian bridges. These bridges have their own special issues in relation to their loading and design, fabrication and construction, and maintenance. This subject should be taught separately as an optional course to bridge engineers involved or wish to get involved in the design, construction and maintenance of pedestrian bridges.

The Sixteenth Lesson: "Bridge Health Monitoring"

Due to the rapid increase of both ordinary and exceptional traffic loads and because of the harshness of the environmental conditions, bridge structures are deteriorating at an alarming rate. Moreover, since the main European and American highways were built around 1950's to 1970's, many important bridges have reached their critical ages of 40-60 years of service at which rehabilitation and retrofit may be needed. In addition, in some countries, the introduction of new national seismic codes requires the assessment of the structural safety and performance of bridges and the prediction of their residual operational life under new seismic loads (e.g. Maalek, 2008) that are higher and new seismic regulations that are tighter than those used at the time of their design. For these reasons, one of the most important and actual challenges in the field of civil engineering infrastructures is concerned with the development of health monitoring facilities and programs to provide a real-time knowledge of critical conditions that may occur in a bridge system (Maalek, 2005).

Some topics in this subject are: different static and dynamic testing procedures (e.g. load testing of bridges, load rating based on load testing), modal analysis (Maalek et al., 2010) and concepts of structural control, smart structures technology, structural identification and health monitoring devices and procedures, radar and GPS based remote sensing methods, fatigue monitoring and damage detection, and data processing techniques. Also, special monitoring techniques and devices applicable to bridges situated in waterways are to be dealt with. These topics are not usually covered in civil engineering university courses and graduated civil and structural engineers are usually unfamiliar with these technologies. This subject is developing very rapidly and the number of bridges having health monitoring systems is increasing throughout the world. Suitable health monitoring plans should be implemented for special or important bridges. The increasing number of papers and reports on this subject being published in an international level indicates the importance of this subject among active researches in bridge engineering. It is clear that in the modern world, a bridge engineer must be well familiar with this subject.

The Seventeenth Lesson: "Bridge Aesthetics"

Quite a number of beautiful historic bridges exist in the world in which form and material properties have been well employed in service of the structural performance and architectural function. Iran is no exception. In addition to some large bridge projects built in the Sassanid era (224 C.E. to 651 C.E.), one may mention the famous Si-o-se-pol and Khaajoo Bridges. Many lessons have been learned from the fact that how bridge engineers have encountered the problems of bridge engineering through centuries. Many historically significant bridges, widely admired by viewers, have given important messages and ideas to contemporary engineers and architects and are considered as key permanent structures. In today's dense and modern cities with their complex transportation systems, the construction of a bridge will affect the surrounding part of the city for at least a century (until the end of its service life). In this regard, a bridge is an important element of a city's landscape and architecture. So is true in the case of highway and railway bridges. Thus the architectural aspects of the design of a bridge, in harmony -or in intentional contrast- with the surrounding areas, are to be taken seriously. The structural form plays a paramount role in the aesthetic properties of a bridge. Hence, bridge aesthetics has to be included in the proposed course covering both the structural and architectural aspects. A presentation of a collection of architecturally significant bridges -both older and more recent bridges- will provide the students of bridge engineering with possible creative approaches to the design of modern bridges (Maalek, 1991). Bridge engineers should also be given training in this field to enable them to make the most of their possible opportunities to create future masterpieces of bridge engineering.

The Eighteenth Lesson: "State-of-the-Art and State-of-the-Practice"

The purpose of introducing the eighteenth lesson is keeping engineers up-to-date with the latest findings and the state-of-the-art in various aspects of bridge engineering versus the state-of-the-practice in the design, construction and maintenance of bridges and bridge project management (for example see: Maalek et al., 2010; Maadani et al., 2015). In addition to recent scientific findings, bridge engineers should be informed of recently built bridges all over the world and their performance. The course may include discussions on recent successful bridge projects, analysis of recent bridge failures, new approaches to bridge rehabilitation and retrofit, recent developments in health monitoring and remote sensing techniques, case studies, et cetera. Such a lesson should be considered as a part of the proposed educational program for engineers and may be presented to professionals in a periodic manner, once every few years, to keep them up to date. Topics may consistently be chosen by the instructor according to recent developments and advances in bridge engineering research as well as actual practice.

Remarks

There are many text books or technical reports, appropriate for teaching each of the previously mentioned lessons, to be selected by every instructor as their teaching reference. Moreover, many of the above mentioned lessons can be presented more effectively, if suitable additional assignments and project works are incorporated in the course program.

Other subjects such as masonry bridges, wood bridges and historical bridges are yet to be dealt with. Also, the finite element modeling and analysis of bridges need special attention, particularly through project works. Subjects such as bridge load rating, soil-structure interaction, the use of composite materials, fatigue behavior and design, vibration isolation, active and passive control and some other special issues may be dealt with in some details within the syllabuses of the above lessons.

Figure 4 is an illustrative diagram representing the educational and training program suggested above to include the essential lessons a bridge engineer needs to learn in order to fulfill his/her job effectively. Therefore, teaching of these subjects to civil engineers should be on top of the agenda of officials responsible for the design, construction, maintenance and retrofit of bridges as well as those authorities responsible for higher education at the post graduate level.

Some of the above mentioned lessons are concerned with general concepts of bridge engineering and hence are useful for all bridge engineers (e.g. bridge deck behavior). There are also courses with special orientation towards a specialized task in bridge engineering (e.g. bridge health monitoring). In the context of a curriculum for bridge engineering education entitled *"Master of Science in Bridge Engineering"*, the proposed lessons can be categorized in mandatory or optional modules.

In the framework of a professional training program, depending upon those aspects of bridge engineering relevant to different needs, it is recommended that selective lessons (e.g. 10 to 12 lessons) to be presented to bridge engineers or newly employed civil engineers in the form of continuous training packages. It is important to present the training courses with more emphasis on the engineering practice, while the basic theoretical concepts are not neglected.

Based upon the above mentioned set of lessons, a new curriculum in graduate level (Master's degree in “*Bridge Engineering*”) can be presented in universities with qualified staff. For this purpose, the above eighteen lessens may be grouped in a number of educational modules as proposed in Figure 5. The first lesson, “*Fundamentals of Bridge Engineering*”, is considered here to be presented as the basic prerequisite course to all students. Some students may have attended and passed such a course as an optional subject during their final year undergraduate studies. Apart from that, four educational modules have been defined each of which containing 4 lessons from the above set of lessons.

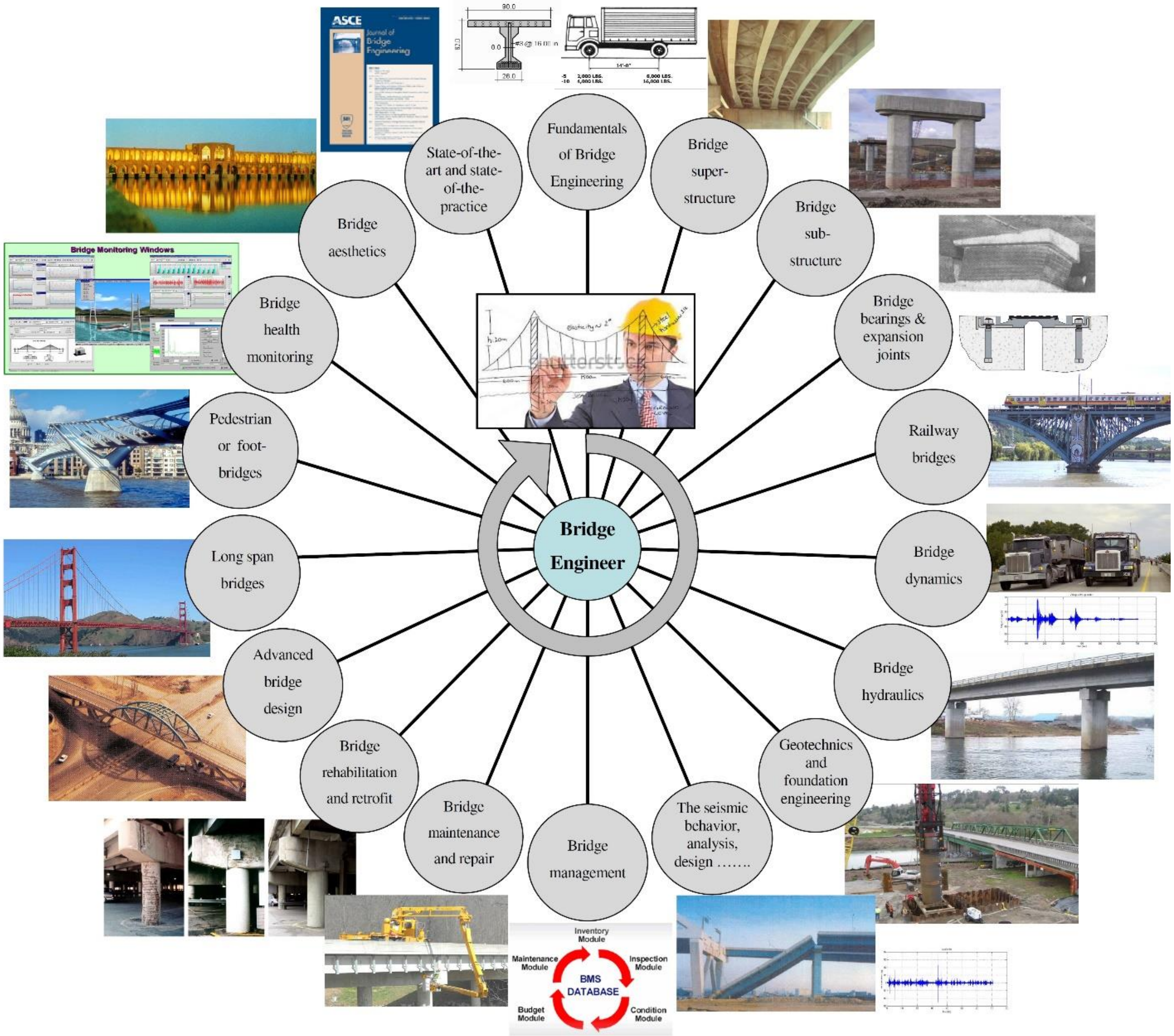
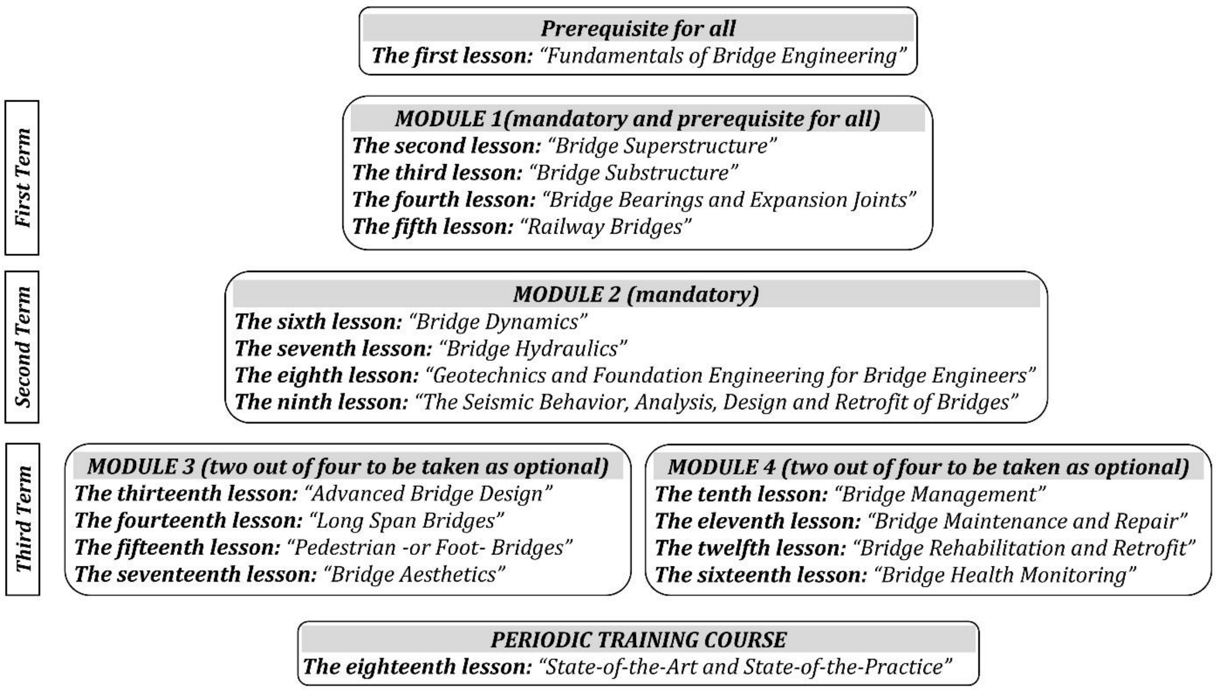


Fig. 4. A graphic representation of the proposed Bridge Engineering training and educational program

The first module has been considered to be mandatory prerequisite module and can be taught in the first term of the Master's program. The second module is also mandatory. However, the group of courses contained in the second module is not regarded as prerequisite for the other courses. The educational content of the above two modules include the main and dominant subjects in bridge engineering. In relation to the two remaining modules, depending on the dominant subject matters in a region or the student's prospective career path, two out of four courses have been considered to be taken as optional from each module. This curriculum should contain a number of well-defined project works and assignments together with a research thesis (dissertation).

In universities having four academic terms (including the summer term), the whole program can be implemented with no difficulties. In universities having only two longer semesters (such as Iran), some of the courses can be merged. For bridge engineers, the professional training programs are easy to handle. For example, each year the engineers can attend a module.



Note:
The courses are designed with projects for professionals and with project works and thesis (dissertation) for university courses

Fig. 5. A new curriculum for Master's degree in Bridge Engineering or training courses for Bridge Engineers

In the case of universities presenting Fall, Winter and Summer terms, four lessons can be included in each term, except for the first term that the program should be so arranged to present the first lesson: "*Fundamentals of Bridge Engineering*" as well. In the case of universities having two semesters, each semester can be divided into two parts for the presentation of the lessons to enable the completion of the prerequisite courses before the others.

In the case of professional training programs, prerequisite and mandatory courses can be presented consecutively in two years' time during their initial years of employment as a trainee engineer. The last four optional courses to be chosen from the 3rd and 4th modules can be taken in the two next consecutive years. Hence, an engineer - with an undergraduate degree in civil engineering or a postgraduate degree in structural engineering- employed in the bridge related industry can complete this program of training in his/her first 4 years of employment as he/she gains practical experience under the supervision of a recognized and experienced professional engineer in an engineering firm or in a related government establishment. After the successful completion of the group of courses in each module, the trainee may be given a certificate indicating that he or she has passed the training program pertaining to that module.

Unless several project works for professional training courses and project works, assignments and research thesis (dissertation) for university courses are included, both the training and the academic programs will not achieve their goals.

After completing one of the above mentioned ways (universities education or professional training), and specific duration of on-site training under guidance of a licensed bridge engineer, the engineer would qualify to get his/her professional license.

Finally, the eighteenth lesson, "State-of-the-art and state-of-the-practice" is meant to be presented to those PhD students who have decided to accomplish their Major and/or Minor research on an aspect of bridge engineering. Such a course has also been considered to be presented periodically to professional bridge engineers in five-year intervals. In other words, irrespective of their experience, professional bridge engineers are suggested to attend this course every five years to learn about recent developments and advances in bridge engineering research as well as achievements in actual bridge engineering practice.

Justification of the Need for the Proposed Program

For many years, it is common in many countries that engineers having an academic degree in Civil Engineering are appointed responsible for different tasks -from design to maintenance- related to all infrastructures and this process is continuing in the world. However, different aspects of civil engineers activities are driving towards more and more application of unique and diverse infrastructures that requires to be responded by professional engineers.

Civil engineers are permanently facing to some other multi- , intra- and cross-disciplines such as: space structures, tunnels and underground structures and also bridges.

In the Vision 2025 for civil engineering and its road map (ASCE, 2007 and 2009), some dreamy goals have been planned for the future of civil engineering profession. For example, a broad promote of civil engineers roles and their partnership/collaboration in decisions shaping public infrastructure policies and in developing new educational and training programs has been emphasized. Many of the programs and tactics in the road map are emphasizing to maximum attendance and partnership of civil engineers in developing professional activities and careers for increasing their roles in development and in the global quality of life. Developing and promoting a universally accepted body of knowledge and skills that prepares civil engineers for professional practice requires that new professional curriculum and educational programs are to be developed and implemented.

In the process used to support the ASCE's Summit in 2006 to develop the Vision 2025, the ASCE conducted an e-mail survey of the membership to determine their opinions on aspirations and visions for civil engineering in 2025. ASCE received 4,382 valid responses to the survey. There was interesting points in the results of the survey. In the first question of the survey, it had been questioned that: "In between the 21 issues specified in the questionnaire, how important developments/trends will be in impacting the civil engineering profession over the next 20 years?" The highest score response was found: "*maintenance of existing infrastructures*" which is a professional and structure type-based activity.

It had also been asked from the respondents that: "What do you think will be the most important issues/developments/trends that will impact U.S. civil engineering and/or the U.S. civil engineer over the next 20 years?" With thousands of responses, a word search tool was used that looked for key words or phrases. The most frequent word was found: "*infrastructure*". It can be concluded that the most important issue that will be impacting civil engineering over the next two decades, in the opinion of the respondents, is "*maintenance of the existing infrastructures*".

These responses are clearly emphasizing that a professional vision and a professional look is needed for infrastructures and this paper attempted to take some steps for bridges as verified representative of infrastructures.

SUMMARY AND CONCLUSION

In this paper, a program of teaching of bridge engineering has been presented. The program has been proposed as a result of an investigation indicating the inadequacy of normal civil engineering undergraduate courses or structural engineering graduate programs in preparing engineers who are involved in bridge engineering profession to fulfill their tasks effectively.

Two routes have been foreseen to fill the gap:

i) An academic route by organizing well-designed and well-presented Master's courses in a number of universities having sufficient specialized teaching staff and relevant facilities. The establishment of such courses should only be made after a thorough evaluation of the ability of the university to present the course with high quality. In the first five years, close supervision and monitoring of the whole activities related to the method and quality of presentation and the competence of the course graduates need be carried out.

ii) A professional training route to familiarize the engineers in the industry and bridge authorities with the theory and practice of bridge engineering to enable them to accomplish their job properly. The program includes lectures, project works and assignments as well as written and oral examinations. A professional certificate should be issued to those who pass the training programs successfully.

For this purpose, the main subjects that a bridge engineer is expected to learn have been outlined above. The authors believe that successful completion of the proposed program aid civil engineers in pursuing a career as a bridge engineer with either, a consultancy, a specialist contractor or a local authority.

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